

Perspective Report Series 7

THE DHARWAR CRATON

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*Department of Mines & Geology
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1. Introduction

THE Dharwar craton occupies a major part of South India in the States of Karnataka, Goa, Andhra Pradesh, and Maharashtra. It is exposed over an area of about 2,50,000sq. km between latitudes 12° N to 22° N and longitudes 74° E to 80° E. It forms a structurally contiguous block and is bound on the west by the Arabian Sea, in the North by the Narmada and Godavari rifts, and in the East and South by the Eastern Ghat Mobile Belt (Fig. 1). The Dharwar craton is essentially a granite-greenstone province.

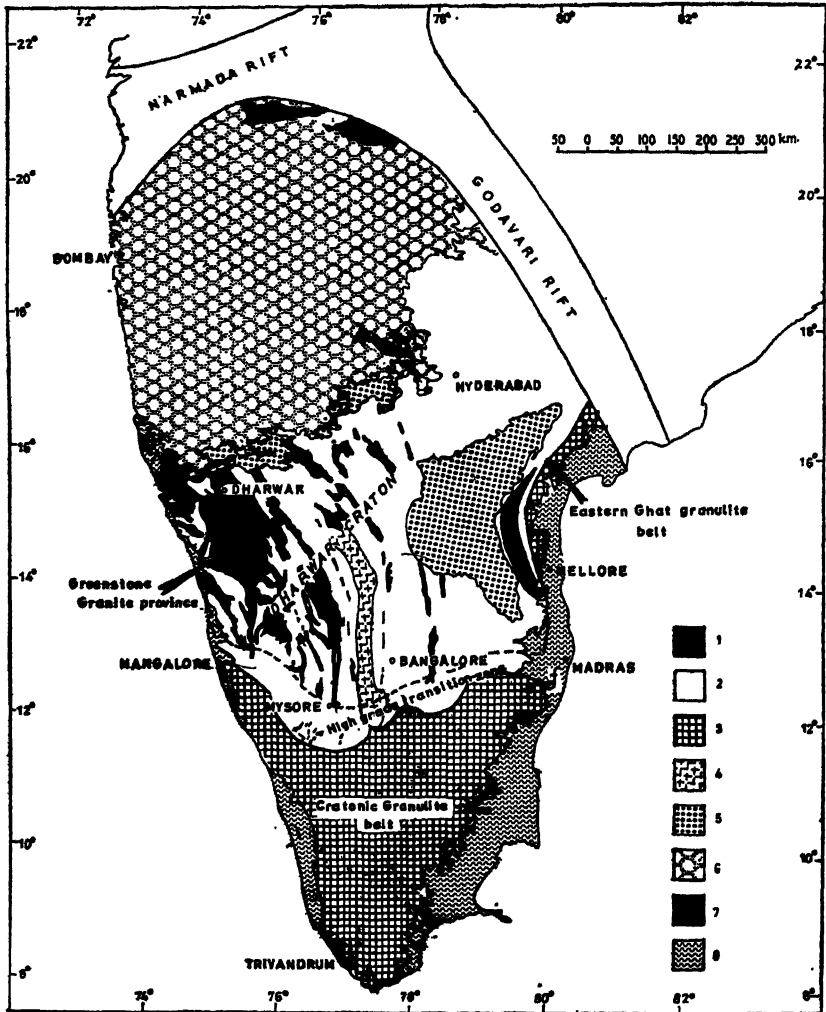


FIG. 1. The Dharwar Craton and its environs.

1. Dharwar supracrustal belts, 2. Peninsular gneiss, 3. Granulite province, 4. Closepet granite, 5. Late Precambrian sediment, 6. Deccan trap, 7. Laterite, and 8. Recent sedimentary cover.

It is composed of early Precambrian low-grade supracrustal rocks preserved in well defined small to large schist belts, and high-grade supracrustals occurring as small schist belts and inclusions in gneisses. Although the high-grade schists are distributed all over the craton, they are more common in the zone bordering the granulite terrain to the East and to the South. The craton is partly covered by younger sedimentary and volcanic rocks. These include the Cuddapah, Kaladgi and Bhima Group sediments of late Precambrian-Eocambrian age, Deccan basalts (traps) of Cretaceous-Eocene age, post-Cretaceous laterites, and Pliocene to Recent coastal and river alluvial deposits.

The geology of the Dharwar craton has been summarised by Pichamuthu¹, Gowda and Srinivasan², Swami Nath and Ramakrishnan³ and Radhakrishna⁴. In Memoir 112 of the Geological Survey of India, Swami Nath and Ramakrishnan^{3,5} have given an account of the views prevalent on the early Precambrian rocks of Karnataka which is the type area for the early Precambrian Geology in India, and also the opinions of a group of officers of the Geological Survey of India which differ in some respects from those of the earlier workers.

The status of knowledge on the early Precambrian Dharwar craton can be summarised under the following main heads:

1. Supracrustal sequence in the Dharwar craton
2. Gneisses
3. Granulites
4. Younger granitoids
5. Geochronology
6. Supracrustal-gneiss relationship
7. Gneiss-granulite relationship
8. Future trends.

2. Supracrustal Sequence in the Dharwar Craton

The meta-sedimentary and meta-igneous (volcanic and plutonic) rocks constituting the schist belts irrespective of their size and grade of metamorphism are included under the term 'supracrustals' in this report.

(a) *Stratigraphy and Subdivision*

After detailed geological mapping the supracrustal rocks in the southern half of Karnataka had been grouped under the name "Dharwar System."⁶ According to Smeeth, there are no rocks older than those in the Dharwar System of Mysore State (now Karnataka). This became the official view of the State Department of Mines and Geology.⁷ Consequent

upon the remapping of the terrain by the Geological Survey of India⁸ a pre-Dharwar supracrustal group of rock formations was envisaged.

The supracrustal rocks in Karnataka are of different metamorphic grades. Low grade metamorphic rocks (greenschist to almandine amphibolite facies) constitute the well-defined schist belts. These have been referred to as greenstone belts following the recent nomenclatural trends in South Africa, Australia and elsewhere. Whereas some consider all the schist belts as greenstone belts, some others believe that there are "true greenstone belts" and "greenstone-like geosynclinal piles" in Karnataka⁹. The true greenstone belts are composed dominantly of metaigneous rocks (mainly volcanic) and the greenstone-like geosynclinal piles have a significant amount of sediments in them apart from the volcanics. These are very similar to the "Keewatin type" greenstone belts and to the so-called "Dharwar type" greenstone belts of Ramakrishnan *et al.*

The high-grade metamorphic rocks (almandine amphibolite to upper amphibolite facies) occur as smaller outcrops amidst gneisses which intrude them. These rock formations by analogy with the Malene and Isua supracrustals of Greenland are believed to be different from the greenstone belt assemblages.¹¹ According to Swami Nath and Ramakrishnan,⁵ the gneisses intrude the high-grade supracrustals, and these gneisses together with the high-grade supracrustal inclusions constitute the basement for the greenstone belts that are composed of low-grade metamorphic rocks. The name "Dharwar Supergroup" has been restricted to the low-grade supracrustal sequence, and the high-grade supracrustals have been placed in another Group—the "Sargur Group"—which is assigned a pre-Dharwar stratigraphic position. The precursors of the Sargur Group are believed to have been deposited, deformed, metamorphosed, and intruded by the gneisses before the precursors of the low grade supracrustals were deposited.

Smeech⁶ classified the "Dharwar System" into a lower 'hornblendic' and an upper 'chloritic' division. Rama Rao⁷ and Pichamuthu¹ had proposed a three-fold division of Dharwars—Lower, Middle and Upper. Radhakrishna¹³ suggested five divisions to which he gave the names Bababudan Series, Dodguni Series, Grey trap Series, Ranibennur Series, and Supa-Dandeli Series. Srinivasan and Sreenivas¹⁴ found that Dodguni and Supa-Dandeli Series were equivalent and that the Grey trap and Ranibennur Series were not separable; overlying the Grey trap-Ranibennur Series was a suite of red beds. They proposed the classification Bababudan Series, Dodguni Series, Grey trap-Ranibennur Series, and G. R. Series. Since 1975, there have been attempts to standardise the nomenclature and prefer lithostratigraphic terms. Iyengar¹⁵ classified the Dharwar supracrustals into Mercara Group, Vanivilas Group, and G. R. Halli-Ranibennur Group. Swami Nath *et al.*¹¹ classified the supracrustals into pre-Dharwar Sargur

Group and Dharwar Supergroup. The entire Dharwar Supergroup has been divided into two Groups, namely Bababudan Group and Chitradurga Group. Radhakrishna and Vasudev¹⁶ have adopted this classification. Radhakrishna⁴ considers that even this subdivision of the Dharwar Supergroup is not justified as the difference between the Bababudan Group and Chitradurga Group appears to be one of differences in facies of deposition only. According to him the two are probably co-eval. Thus, whereas the late sixties and early seventies saw attempts for more detailed classification of the Dharwar supracrustals, since 1976 there appears to be an opposite trend.

There is no general agreement on the criteria and number of subdivisions of the supracrustal sequence. Angular unconformities between Peninsular gneiss and Dharwar, and Sargur and Dharwar have been proposed based on axial plane cleavage-bedding intersection; no detrital minerals or rocks of Sargur Group have been found in the Dharwar sediments; and no magmatic or sedimentary rocks peculiar only to the Sargur Group have been identified. It is, therefore necessary to evolve a stratigraphical classification that can satisfy tectonic, magmatic, and sedimentological criteria.

(b) Structure

No detailed structural studies have been made in the Dharwar craton. In recent years, Chadwick *et al.*,¹⁷⁻¹⁹ Janardhan *et al.*,²⁰ Roy,²¹ Mukhopadhyay *et al.*,²² Naha and Chatterjee,²⁴ Roy and Biswas²⁵ and Naha *et al.* (unpublished) have contributed to a preliminary understanding of the structures.

Chadwick *et al.*¹⁷ recognised three episodes of deformation in the rocks of "Sargur Group" and "Dharwar Supergroup". The earliest structures in both are isoclinal folds which have been nearly co-axially refolded by upright folds which are open to tight. The third generation folds have their axial trace and axis at high angles to the earlier folds of the first two generations. They are very broad openwarps on the schistosity surfaces. In style, sequence, and orientation, the folds in the Dharwar and Sargur supracrustals were found to be identical. This coincidence was expressed by Chadwick *et al.*¹⁷ as $SgD_1 = DhD_1$; $SgD_2 = DhD_2$; and $SgD_3 = DhD_3$, where SgD stands for Sargur deformation structures and DhD for Dharwar structures. This coincidence was considered to be due to drawing of Sargur structures into parallelism with the structure of Dharwar Supergroup during Dharwar tectonism. Naha *et al.* (unpublished) have also noticed the unity of structures in the Dharwar and Sargur supracrustals. However, as it would not be possible mechanically to cause parallelism of structures of successive generations if the Dharwar deformation post-dated

the three episodes of Sargur deformation, they are inclined to believe that the Dharwar and Sargur supracrustals were deformed simultaneously. Another possibility by which such a parallelism can be achieved is that SgD₁ was followed by DhD₁ when the SgD₁ structures were drawn into parallelism with DhD₁ and subsequent deformations affected both the sequences together. In either case there is no definite break apparent between the Dharwar and Sargur supracrustals as envisaged by Swami Nath and Ramakrishnan⁵.

(c) Petrology and Geochemistry

High-Grade Supracrustal Rocks—The rock formations in the high-grade supracrustal Sargur Group are given in Table 1.

TABLE I : Major lithotypes of Sargur belt

Metaultramafites and metabasites
Hypersthene-hedenbergite-amphibole-magnetite-quartz (ironstone)
Garnet pyroblastite and amphibolite (metabasite)
Crystalline limestone, dolomite, and calc-silicate rock
Sillimanite-garnet-staurolite-kyanite-graphite-corundum—biotite - K. feldspar-plagioclase-quartz schist and paragneiss interbedded with metabasite.
Quartzite, quartz-fuchsite-muscovite schist with sillimanite, kyanite, graphite, garnet and staurolite with bedded barytes.

(after Viswanatha and Ramakrishnan, 1981)

There is no agreement on the nature of the precursors of these high-grade supracrustal rocks.

The fuchsite quartzites, the metapelites and the metacarbonate rocks are believed to have been derived from deposits accumulated over a sialic base in a shelf type environment^{16,26} or in shallow basins of limited extent.⁴ On the basis of geochemical evidence, however, Naqvi⁹ and Glikson²⁷ believe that the precursors of high-grade metamorphic rocks must have been derived from an essentially simatic provenance as they are characterised by high levels of Mg, Fe, Cr, Ni, and Mn. Oxygen isotopic studies of fuchsite quartzites have indicated that they may be recrystallised cherts, but not detrital orthoquartzites.²⁸ Raase *et al.*²⁹ have shown that fuchsite quartzites of both detrital and chemical origin occur. Low yield of heavy mineral fraction, especially the near total absence of zircons in some of the fuchsite quartzites supports the contention of their having been chemical precipitates. Fuchsite quartzites of chemical origin associated with barytes are also known.^{29,30,31,32} Quartzites and quartz schists with silicate minerals like kyanite, sillimanite, sericite, fuchsite etc. apparently have been derived from semipelites and immature quartzites. The impure

pelite-dolomite admixtures appear to have been the precursors of the amphibolites that are usually garnetiferous. Marbles with some calc-silicate minerals (diopside, scapolite, phlogopite) may have been derived from purer carbonate beds. The iron formations are dominantly silicate bearing types.³³ In places where the ferruginous sediments are manganiferous, manganoean pyroxene and spessartine garnet have formed; elsewhere hypersthene, hedenbergite and almandine-pyrope garnet are common.^{33,34} According to Srinivasan (in preparation) the abundance of silicates in the iron formations suggests that these iron formations were of non-oxide type. Based on the distribution co-efficients of temperature and pressure sensitive elements between co-existing minerals Rollinson *et al.*,³⁵ Harris and Jayaram,³⁶ and Raith *et al.*³⁷ have estimated the P-T conditions of metamorphism of Sargur Group rocks. The P-T ranges proposed by these authors is summarised in Table II.

TABLE II : *Pressure and temperature estimates for the high-grade supracrustals of Dharwar craton*

Area	Temperature °C	Pressure Kb	Reference
Sargur area, south of Mysore	690±60	7.6	Raith <i>et al.</i> ³⁷
Sargur region (western block)	790±50	13±2	Rollinson <i>et al.</i> ³⁵
Sargur area	700		Varadarajan and Verma, 1982 ^{48a}
Bangalore-Kunigal-Satnur area	760	6	Raith <i>et al.</i> ³⁷
Bangalore-Kunigal-Satnur area	700-800	5-7	Harris and Jayaram ³⁶

According to Swami Nath and Ramakrishnan⁵ the eastern and western parts of Karnataka evolved in two different tectonometamorphic blocks, the eastern characterised by low pressure metamorphism (indicated by stability of andalusite) and the western by intermediate pressure facies series (indicated by stability of kyanite). This view was supported by Rollinson *et al.*³⁵ As applied to the whole of the Dharwar craton this view does not hold good because kyanite occurs in the Khammam and Nellore schist belts, the latter situated in the eastern most part of the craton. Studies over a wide region both in the low and high-grade terrains suggested to Raith *et al.*³⁷ that at least in the high-grade terrain of southern Karnataka, there was no such distinction apparent. Raith *et al.*³⁷ and Harris and

Jayaram³⁶ have confirmed the earlier view of Srinivasan and Tareen³⁸ that the meridional Closepet granite region is a zone of low pressure metamorphism and have also supported the conclusions of early workers like Pichamuthu³⁹, Radhakrishna¹³, Ananta Iyer⁴⁰, and Ananta Iyer and Kutty^{41,42} that there is an increase in the grade of metamorphism from north to south in Karnataka. Despite the fact that these observations are based on over 500 electron microprobe analyses, for a vast region like the Dharwar craton, the data can still be considered inadequate and further work is necessary to establish more firmly the P-T regimes and also to trace the temporal changes in the P-T conditions in relation to the tectonic evolution of the terrain.

Associated with the metasediments of the Sargur Group are suites of ultramafic-mafic rocks and anorthosites. These are well exposed in the type area to the south of Mysore and also in the southern part of Holenarasipur belt. The chromite and titaniferous magnetite bearing ultramafic-mafic suite of the Nuggihalli belt is also considered to belong to the Sargur Group, although they are of a much lower metamorphic grade.⁵ Divakara Rao *et al.*⁴³ consider that the ultramafic rocks south of Mysore are metamorphosed peridotitic komatiites. According to Naqvi,¹⁰ such komatiitic ultramafic rocks constitute the lowermost members in the greenstone belt of Holenarasipur, and the associated anorthosites are similar to lunar anorthosites⁴⁴ and therefore, the early Archaean crust in India was of anorthosite-norite-troctolite type as on the moon.⁴⁵

The ultramafic rocks of Holenarasipur and Nuggihalli are believed to be komatiitic as they exhibit pillow structures^{28,46} and spinifex textures.⁴⁷ According to Varadarajan,⁴⁸ the ultramafic rocks are alpine type cold intrusives. Srinivasan and Sreenivas,⁴⁶ Vasudev and Srinivasan⁴⁹ and Nijagunappa and Naganna⁵⁰ however, consider them as deformed layered intrusions. Petrochemical studies by Srikantappa *et al.*⁵¹ have shown that the chrome spinel in the ultramafics of Sargur region (Sinduvalli) have chemical composition similar to those in stratiform complexes. Microprobe analyses also show that the chromites of the Nuggihalli belt are rich in iron probably more than even in layered intrusions (Srinivasan and Glikson, *unpublished*). The ultramafic-mafic suite which is considered to be at the base of the older greenstones⁹ are believed to be intrusive into the Sargur Group metasediments by Srikantappa *et al.*⁵¹ and Viswanatha and Ramakrishnan.²⁶

Low-Grade Supracrustal Rocks—Low-grade supracrustal rocks that are now grouped under the Dharwar Supergroup consist of metavolcanics and metasediments which by virtue of their association and internal structures can be considered as deposits in stable and mobile zones of sedimentation.^{4,12,52} The stable zone volcano-sedimentary association consists of

(1) oligomictic conglomerate-quartzite-mafic/felsic lava-banded iron formation association (Plate I), and (2) oligomictic conglomerate-quartzite-carbonate-banded manganese-iron formation association with minor mafic volcanic rocks (Plate II). The mobile zone association consists of poly-mictic conglomerate-greywacke-mafic/felsic lava-iron formation association (Plate III)^{14, 52, 53}. There is no agreement as to whether the carbonate (limestone and dolomite) and manganese formations should be clubbed with the stable zone association (Dodguni Subgroup) of Pichamuthu and Srinivasan⁵³ or with the mobile zone association (Chitradurga Group) of Swami Nath and Ramakrishnan⁵ or are transitional zone sediments deposited between the two.⁴

The petrology of low-grade supracrustals is somewhat better known. The metavolcanics are represented by basic volcanics often with pillow and variolitic structures. Plagioclase quench structures are common, pyroxene quench textures have been suspected, but definite olivine quench textures have not been reported so far. The basic volcanics are associated with rhyolites and rhyodacites, and tuffs and volcanic agglomerates. Andesites and dacites are present, but somewhat rare in the volcanic sequence. Geochemistry of these volcanic rocks has been studied in some detail. The mafic volcanics of the Bababudan Group are tholeiitic, spilitised to various degrees, and are derived from a Zr and LREE enriched mantle.⁵⁴ The basic sills associated with the orthoquartzite-limestone sequence of the Dodguni Subgroup have chemical composition comparable to that of the volcanics of the Bababudan Group. The volcanic rocks of the Chitradurga Group are also tholeiitic, but do not show significant enrichment of LREE or Zr in contrast to the Bababudan volcanics.^{53, 55} Some of the mafic volcanics in the Kolar schist belt have komatiitic chemical composition although textural evidences are wanting to confirm their komatiitic nature. A survey of the available chemical data, however, shows that komatiites are rare in the Dharwar sequence. The chemical composition further suggests that the volcanic rocks can be compared with mafic volcanics of continental margin environments, some of them having compositions similar to island arc basalts and others similar to marginal basin basalts.⁵⁶ There are indications that more than one suite of basalts with distinctive chemical characteristics may be present in Dharwar schist belts (one corresponding to ocean floor basalts and another to continental margin type), but this needs confirmation.

The platform sedimentary rocks consisting of oligomictic conglomerates, quartzites, metapelites, and limestones are among the least studied sedimentary rocks of the greenstone belts. Sedimentological studies of rocks in the Dharwar craton are very inadequate.⁴ The oligomictic conglomerates at the base of the Bababudan sequence are composed of vein quartz

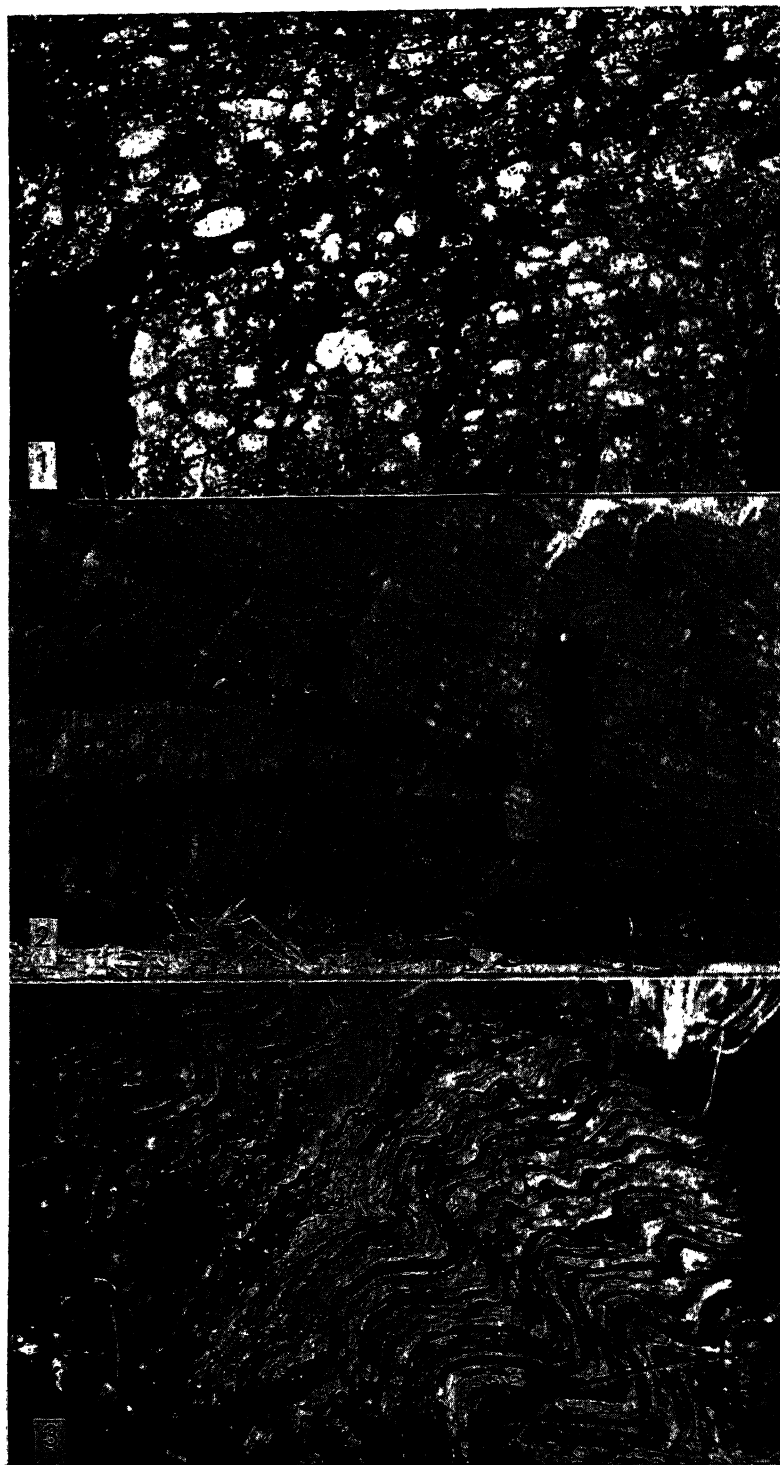
PLATE I (For caption *see* p. 15)



PLATE II (For caption *see* p. 15)

PLATE III (For caption *see* p. 15)

pebbles in a quartzitic matrix. The pebble to matrix ratio varies from 60:40 to 80:20, and most commonly, therefore, the conglomerate is a clast-supported variety. Apart from quartz in the matrix, fuchsite, pyrite, rutile, zircon (dark brown), magnetite and chromite are known among the heavy minerals. The quartzites vary in composition from quartz arenites to impure fuchsitic and sericitic quartzites. Most quartzites are chemically immature when their alkali ratios vs silica-alumina ratios are considered. Some of the metapelitic rocks are graphitic, but the nature of the graphitic carbon is not known. The iron formations of the Bababudan Group shows variation from dominantly silicate to oxide facies.

The quartzites of the Dodguni Subgroup are also chemically immature. Although the associated metapelites are more alkalic, they are characterised by high Fe-Mg and related trace elements. The banded manganese formations are very similar to the banded iron formations except that they have manganese oxides (psilomelane, pyrolusite, manganite, jacobsonite) and carbonate (todorokite) in Mn-rich bands that alternate with quartz-rich bands. Metamorphism has recrystallised the earlier chert bands to quartz which on weathering becomes saccharoidal. The primary mineralogy of the banded manganese formation is not known.

There are both limestones and dolomites of primary origin. The occurrence of primary limestones in Archaean sequence is very rare and the Dharwar limestones, therefore, appear to attain great significance in this respect. Preliminary carbon and oxygen isotopic work by Kumar and Saxena⁵⁷ indicates mean $\delta^{13}\text{C}$ values vs PDB is -0.5 and mean $\delta^{18}\text{O}$ value vs SMOW is $+17.7 \pm 1.4$ per cent suggesting some organic activity. Pichamuthu⁵⁸ found filamentous algal bodies in the cherts of the Dodguni

PLATE I. Some typical rock formations of the Bababudan Subgroup

1. Oligomictic conglomerate : base of Bababudan sequence. Kartikere near Chikmagalur. Bababudan greenstone belt.
2. Cross bedded quartzite. 11km from Chikmagalur on Kadur road. Bababudan greenstone belt.
3. Banded iron formation. Kemmangandi. Bababudan greenstone belt.

PLATE II. Some typical rock formations of Dodguni Subgroup.

1. Cross bedded quartzite, Dodguni. Chitradurga greenstone belt.
2. High calcium limestone. Melekote. Chitradurga greenstone belt.
3. Banded manganese formation. Supa. Shimoga greenstone belt.

PLATE III. Some typical rock formations of the Chitradurga Subgroup.

1. Polymictic conglomerate showing graded bedding. Kaldurga. Bababudan greenstone belt.
2. Pillow structures, Maradihalli. Chitradurga greenstone belt.
3. A carbonate facies iron formation. Near Kereyaganahalli. Chitradurga greenstone belt.

area and Suresh⁵⁹ has shown that the algal filaments are of syngenetic nature. The role of this early biological activity in promoting the deposition of iron and manganese formations, cherts, limestones, dolomites and other non-detrital sediments has not been studied.

The major and trace element geochemistry of the sedimentary rock formations of the Chitradurga Group are better known. The polymictic conglomerates occurring at the base of and within the Chitradurga Group are composed of a mixed assemblage of pebbles—tonalites and trondhjemites^{60,61}, hornblende biotite schists, banded iron formations, quartzites, and conglomerates. Some of the pebbles can be traced to the rocks in the Bababudan sequence. The pebbles of tonalites and trondhjemite do not resemble in composition the Peninsular gneisses which occur in the neighbourhood of conglomerates. The matrix of the conglomerates and the greywackes have high levels of ferromagnesian trace elements. The presence of granitoid pebbles and the high proportion of ferromagnesian trace elements can be reconciled if there was a mixed provenance in which there was a significant mafic component. The exact role of sedimentary differentiation and also that of the provenance in controlling the composition of sediments has not been properly investigated in the Dharwar craton. The REE abundances have been used elsewhere⁶² to assess the changing nature of the provenance in relation to the temporal evolution of the continental crust. REE studies on Dharwar sediments are too scanty to get an insight into the provenance. The iron formations associated with the Chitradurga Group show distinct facies variations from oxide through carbonate to sulphide facies^{4,14,52}, which could imply that the iron formations are chemical precipitates, but not colloidal deposits. Sulphur isotopic studies from the sulphide facies iron formation have indicated that the sulphur for the sulphidic iron formation was derived from a mantle source⁶³ indicating a genetic link between the iron formation and volcanism in the terrain. The mode of origin of the iron formation, however, is still very little understood.

3. Gneisses

Smeeth⁶ classified the granitoids of the Dharwar craton in Karnataka (then Mysore State) into four kinds which, in chronological sequence, are: Champion gneiss, Peninsular gneisses, Charnockite, and the Closepet granite. All these were believed by him to be igneous intrusives. Later investigations have shown that the Charnockites are of metamorphic origin and constitute a part of the granulite province and are not typical of the greentone-granite Dharwar craton.

(a) *Nomenclature*

The name Champion gneiss was given to the earliest acid igneous rocks intrusive into the Kolar schist belt. The Champion gneiss, named

so because of its presumed genetic relation to the Champion lode of the Kolar Gold Field, is characterised by the presence of opalescent blue blebs of quartz.

The name Peninsular gneiss was given to a suite of gneisses which are extensively developed in Peninsular India and which bear an intrusive (younger) relation to the Dharwar schists as opposed to the Fundamental gneiss which, elsewhere in India, are known to underlie the equivalents of the Dharwar schists.

The name Charnockite was adopted in the Dharwar craton for the hypersthene-bearing rocks similar to those described from Madras by Holland⁶⁴.

Closepet granite was named after the town of Closepet, now called Ramanagaram, a town about 55km west-southwest of Bangalore on the Bangalore-Mysore road. It is a porphyritic granitic rock consisting of pink or grey feldspar phenocrysts and occurs in a well-defined zone from Closepet in the South to Bellary and beyond in the North. The rock formation was earlier designated as Bellary gneiss by Bruce Foote.⁶⁵

In later years, rocks with opalescent quartz irrespective of whether they were of igneous intrusive origin or not, came to be referred to as Champion gneiss.⁶⁶ This approach diffused the definition and significance of the term Champion gneiss. In recent years, gneisses with basement relation to the supracrustals and gneisses which are younger than the supracrustals have both been referred to as Peninsular gneiss. Such indiscriminate usage had led to the notion that the terms Champion gneiss and Peninsular gneiss are "basket terms" and, therefore, have no stratigraphical value. Because of later misuse the very purpose for which they were proposed has been defeated. There is a clear necessity for standardising the nomenclature, since, it has now become necessary to state what each author means when he uses the terms Dharwar, Peninsular gneiss, etc.

(b) Structure

The nature of deformation of the gneisses in the Dharwar craton is not clearly known. Preliminary investigations by Naha *et al.* (*unpublished*) show the following important features.

Structures in the Dharwar supracrustals are duplicated in the Champion gneiss. But Champion gneiss shows evidence of postcrystalline deformation to varying degrees. The brittle deformation is accompanied by intense sericitisation, chloritisation, development of solution quartz with pinch and swell structures, and ductile folding. These features indicate an early synkinematic age for the emplacement of Champion gneiss with reference to the folding episode of the Dharwar supracrustals.

In contrast to Champion gneiss, the Peninsular gneiss is characterised by ductile deformation features and absence of post crystalline deformation except along decipherable later fault zones (Plate IV). There is a structural unity exhibited by the Peninsular gneisses and supracrustals of both high- and low-grade. There are evidences of changing ductility of rocks during the migmatisation accompanying deformation. The nature of the deformation in gneisses can be of great significance in understanding the prekinematic or synkinematic nature of the gneisses. Peninsular gneiss is considered to be the basement for the Dharwar Supergroup by Swami Nath and Ramakrishnan,⁵ but as synkinematic with Dharwar deformation, and therefore, younger than the Dharwar supracrustals by Srinivasan and Sreenivas,¹⁴ Srinivasan *et al.*,⁶⁷ Pichamuthu⁶⁸, and Pichamuthu and Srinivasan.⁶³ The structural features in the Peninsular gneiss support the contention that this gneiss is synkinematic with Dharwar deformation.

Most of the Closepet granite has a gneissic aspect. The gneissic Closepet granite has isoclinal folds in common with the Dharwar supracrustals and Peninsular gneiss which suggests that potash metasomatism occurred quite early in the tectonic evolution of the terrain. There are instances of pegmatite veins bearing potash feldspar participating in the first generation isoclinal folding in the over 3000m.y. old Channarayapatna gneisses.⁶⁹ Therefore, from a structural point of view, the Closepet granite which has been considered as "younger granitoid" in the Dharwar craton may actually be much older than generally believed.

(c) Petrology and Geochemistry

The knowledge on the petrology of the gneisses of the Dharwar craton is also somewhat preliminary.

Champion gneiss is a fine to medium grained rock with megacrysts of quartz, oligoclase and microcline in a fine grained groundmass. Biotite is the dominant mafic mineral. Hornblende is also present. Sericite is secondary after feldspars. The minerals show evidence of post-crystalline deformation of various degrees. Compositionally the Champion gneiss has a range from quartz monzonite to granite.⁷⁰

Peninsular gneiss which is the most dominant rock formation of the craton is usually grey banded or foliated exhibiting a variety of migmatitic

PLATE IV. Some structural features of the Peninsular gneissic complex. →

1. Agmatitic structure. Kathriguppe quarry, Bangalore.
2. Veined gneiss showing ductile deformation and evidence of superposed folding, Kallasomanahalli near Nuggihalli.
3. Veined gneiss showing ductile deformation and healed shears. Kallasomanahalli near Nuggihalli.



PLATE IV (For caption *see* p. 18)

structures.⁷¹ In contrast to Champion gneiss, the Peninsular gneisses, except along later fault zones, do not contain evidences of post-crystalline deformation. However, Ramakrishnan and Viswanatha⁴² state that they show brittle deformation features along the margins of schist belts.

Peninsular gneiss has a wide range of composition from trondhjemite to granite. On an FMA diagram they define a calc-alkaline trend. It is a complex of granitoids developed over a large span of geological time. Three phases have already been recognised—around 3400, 3000 and 2600m.y. ago. Investigations are inadequate to prove whether there is a secular change in the composition of these gneisses. Preliminary investigations indicate that the 3400m.y. old gneisses are tonalitic. The 3000m.y. old gneisses are tonalitic to adamellitic in composition. The 2600m.y. old gneisses appear to be richer in K₂O than the earlier ones. Initial strontium isotope data available for the gneisses of the region suggest igneous precursors for most of the Peninsular gneisses.⁷³ The Sr isotope ratio lies within error of a bulk earth growth curve, and, therefore, Drury *et al.*^{44a} believe that the gneisses older than 3000m.y. in the Dharwar craton were differentiated from a mantle like source or at the most had a short crustal history. Jayaram⁷⁴ from a study of REE patterns has shown that Peninsular gneiss is strongly depleted in HREE and, therefore, garnet or hornblende could be dominant in the residue in the mantle from which the melt for Peninsular gneiss was derived.

Although an igneous origin for most of the Peninsular gneiss is suggested by the observations made earlier, it must be mentioned that the Peninsular gneiss is a complex consisting of both ortho- and para-gneisses. Divakara Rao *et al.* and Naqvi *et al.*⁷⁴ have described the para-nature of some portions of the Peninsular gneissic complex. The occurrence of inclusions of metasediments in the various stages of migmatization, the presence of rounded zircons apart from euhedral zircons in them, the high TiO₂ content in some of the gneisses and especially in those that occur at the border of the supracrustal belts, point to the role of supracrustals in the evolution of Peninsular gneiss. Detailed mapping and petrological and geochemical studies are necessary to resolve the complexity of Peninsular gneiss.

Closepet granite occurs in an arcuate zone parallel to the trend of the major Dharwar supracrustal belts. The zone is about 30km to 50km wide in which stocks and bosses of granitoids occur amidst Peninsular gneisses. The Closepet granite is made of several types of potassic granites, the conspicuous variety being a porphyritic rock with grey and pink feldspar megacrysts. Inclusions of gneisses and supracrustal rocks are found within the granites. The development of megacrysts of potash feldspar is attributed to the effect of potash metasomatism through the influx of late-stage potash-rich solutions along a belt of weakness in the earth's crust.⁷⁷ The origin of

Closepet granite by metasomatic granitisation has also been suggested by Divakara Rao⁷⁸ and Divakara Rao *et al.*^{79,80} Geochemical studies show that the development of Closepet granite from Peninsular gneiss was accomplished through a process of enrichment of Si, K, Rb, Pb and Th and depletion of Ca, Mg, Fe, P, Ti, Sr and Cs. Friend⁸¹ believes that the Closepet granite has been formed by a process of anatexis and partial melting of Peninsular gneiss, and has suggested that the development of K-rich Closepet granite and charnockite from the Peninsular gneiss are probably co-eval and related phenomena.

4. Granulites

Granulites are well developed in the southern portion of the Dharwar craton. They constitute the Eastern Ghat mobile belt that borders the Dharwar craton to the east and southeast. Field geological, petrological and geophysical investigations show that the greenstone granite province of the Dharwar craton passes into the high-grade granulite province by transition in the southern parts of the craton.^{82,83,84} The granulites of the Dharwar craton are very significant, because here is unique preservation of an arrested stage of charnockitisation of gneisses,^{85,86,87,88} which has provided an opportunity for investigating the processes responsible for their formation.

(a) Structure

Charnockites are characterised by planar and linear structures similar to those in gneisses. In the high-grade terrain in which transition to charnockite occurs in the Dharwar craton, the charnockites exhibit well-developed gneissosity. Naha *et al.* (*unpublished*) have observed that charnockites occupy crescent-shaped low pressure zones of the isoclinal fold cores of first generation folds affecting the entire Dharwar craton. The charnockites also occur as pockets in boudin necks in the migmatites of Peninsular gneiss suite. Boudinaged charnockites aligned parallel to gneissosity have also been observed. Charnockites also occur as cross-cutting veins.^{85,86,87,88,87} The aforementioned structures indicate that charnockites were already formed when the compressive strain which caused F1 buckle folding in the Dharwar craton was in operation. The charnockites may therefore be considered as syn- to late-tectonic with reference to F1 folding in the Dharwar craton. Raith *et al.*⁸⁷ have, however, attributed charnockitisation to a late- to post-tectonic process.

(b) Petrology and Geochemistry

The charnockites of the Dharwar craton were shown to be of metamorphic origin by Rama Rao⁸⁹ and Pichamuthu^{88a,90}. They recognised an

increase in the grade of metamorphism from North to South in the Dharwar craton, culminating in the granulite grade in the southern portion. This view found support from a study of the chemistry of feldspars, garnets, and amphiboles.^{40,41,42} Pichamuthu⁴⁵ described the development of charnockites from Peninsular gneiss in the Kabbaldurga quarries, which fall within the zone of transition from amphibolite to granulite facies. In recent years, Janardhan *et al.*^{87,88} Harris and Jayaram,⁸⁶ Friend,⁸¹ Mahabaleswar and Naganna,⁹¹ Allen *et al.*⁹² and Raith *et al.*³⁷ (preprint) have contributed to the geochemistry and geothermobarometry of the granulite formation.

Janardhan *et al.*⁸⁸ and Allen *et al.*⁹² have observed that the conversion of gneisses to charnockites is virtually isochemical when both major and trace elements are considered. Allen *et al.*⁹² consider that in the transition zone, migmatitic tonalitic-trondhjemitic gneisses, granitic gneisses, and charnockites constitute the three principal rock formations. The contact between the tonalitic gneisses and charnockites as well as between tonalitic gneisses and granitic gneisses is gradational. Granitic gneisses are seen to decrease away from the tonalitic gneiss-charnockite contact zones. Whereas the compositions of the tonalite-trondhjemitic gneiss and charnockite are similar the granitic gneiss is somewhat more enriched in K, Rb, Ba, Th and LREE. The compositions of charnockite and tonalitic gneisses are similar to those of high Al_2O_3 Archaean tonalites.

The isochemical transformation of the gneisses to charnockites appears to have occurred in southern Karnataka at 700 to 800 °C and pressures of the order of 5 to 7kb, and that H_2O pressures were 0.1 to 0.3 times of the total pressure. The metamorphism was accompanied by high CO_2 influx.^{87,88} According to Raith *et al.*³⁷ the charnockites of the Sargur area south of Mysore give P-T estimate of 7.5kb. and 740 °C.

5. Geochronology

When compared to the many stratigraphic problems presented by the terrain, the geochronological data may be said to be totally inadequate. Venkatasubramanian⁸³ reviewed the geochronological data available till 1975 which indicated the following trends :

1. Rb-Sr isochrons for Dharwar lavas are not satisfactory because of poor rubidium enrichment.
2. Relict ages of granitoids as old as 3300m.y. are found in the pebbles in the Dharwar conglomerates.
3. Rb-Sr whole rock and mineral isochrons suggest that two major events are recognisable in the granites and migmatites of the region: one at 2900–3000m.y. and another at 2500–2600m.y.

4. The 2600m.y. event is also reflected in the charnockites.
5. A late granitic event at about 2000m.y. is observed in the Closepet granite suite.

Glikson⁹⁴ has summarised the recent geochronological data. The oldest ages documented in the Dharwar craton include a 24 point Rb-Sr whole rock isochron of 3315 ± 54 m.y. ($R_i = 0.7006$) and a 11 point Pb-Pb isochron of 3305 ± 13 m.y. for the Gorur-Hassan tonalitic gneisses of the Holenarasipur region.^{95,96} Monrad *et al.*⁹⁷ refer to a 3800m.y. U-Pb zircon age by A.L. Odom for the low-Rb Gorur-Hassan gneiss. The Gorur-Hassan gneiss carries inclusions of metamorphosed supracrustals which are believed to be xenoliths by Hussain and Naqvi,⁹⁸ but are considered as tectonic inclusions by Beckinsale *et al.*⁹⁶ It is necessary to establish the exact nature of these inclusions for understanding the relative age relationship of the supracrustals and gneisses.

Drury *et al.*^{44a} have reported an Rb-Sr isochron age of 3280 ($R_i = 0.7009 \pm 12$) for the Hirebelle gneisses in the Western Ghat region of Karnataka. These gneisses have ages similar to that of the Chikmagalur tonalite whose Pb-Pb age is 3200 ± 70 m.y.⁹⁹ The Chikmagalur tonalite is considered to be the basement for the Bababudan Group by Swami Nath and Ramakrishnan.⁵ But apophyses of the Chikmagalur granitoid are found in the Chikmagalur conglomerate which is at the base of the Bababudan Group^{28,58} (also Naha *et al.*, *unpublished*). The metavolcanics of the Kudremukh region which are believed to be the equivalents of the volcanics of the Bababudan Group⁶ have given an Sm-Nd age of 3020 ± 230 m.y. ($R_i = 0.50878 \pm 22$).^{44a}

Bhaskar Rao *et al.*,^{54a} and Monrad *et al.*⁹⁷ have dated the gneisses in the vicinity of the Holenarasipur schist belt. The gneisses to the east of the belt have given a Rb-Sr age of 3000 ± 10 m.y. ($R_i = 0.70323 \pm 0.00035$). The gneisses (Halekote trondhjemites) to the north of the belt are 3070m.y. old which is presumed to be a metamorphic age.

Some of the cordierite gneisses of southern Karnataka broadly falling within the zone of Closepet granite have given an Rb-Sr age of 3010 ± 90 m.y. ($R_i = 0.701 \pm 0.001$).¹⁰⁰ The Peninsular gneisses around Bangalore have yielded Rb-Sr ages of 2950m.y.⁹⁸

The Chitradurga granite known to intrude the Chitradurga Group has yielded a lead isochron age of 2605m.y.⁹⁹ and an Rb-Sr age of 2500m.y.

The intrusive granitoids, therefore, fix a minimum age for the supracrustals of the region between 2605 and 3200m.y. They are probably older than 3315m.y. or even older than 3800m.y.

6. Supracrustal-Gneiss Relationship

Discussion on supracrustal-gneiss relationship in the Dharwar craton centres mainly around the relative ages of the Peninsular gneiss and the supracrustals. Pichamuthu⁶⁸ has made a critical analysis of the problem. The various aspects of nomenclature, structure, petrology, geochemistry, and geochronology presented in the preceding sections have a bearing on the supracrustal-gneiss relationship.

Bruce Foote⁶⁵ separated the "Archaean rocks" from the "Dharwar System" and considered that the volcanic and sedimentary rock formations of the Dharwar System accumulated on Archaean rocks dominantly composed of gneisses. Although he believed that the Dharwar system was generally younger, it is obvious from the following excerpts⁶⁵ that he was not sure of the relative age relations :

"They (*the Archaean rocks*)* present a great variety consisting as they do of granites, gneisses, schists of many kinds, quartzites, trappoids whose interrelations have yet to be worked out before they can be referred to different groups." (p.2).

"The question of several rather striking bands of schistose rocks, bearing some resemblance to the Dharwars, has already been referred to before, when it was pointed out that their true position, whether Archaean or Dharwadian, could only be decided by much closer study than it had been possible to devote to them up to date". (p.5).

It is probably because of this uncertainty that Bruce Foote^{65a} showed all the schists in one colour in his geological map.

The first authentic geological mapping of Mysore State was completed by 1915 which showed both the high- and low-grade supracrustals as belonging to the Dharwar System.⁶ It was shown that gneisses are intrusive into both the high- and low-grade schistose rocks and, therefore, are younger. Since then, all the schists have been considered as belonging to the Dharwar System and the gneisses intruding them as Peninsular gneiss.^{1,7}

There is general agreement that the gneisses are intrusive into the high-grade supracrustals; but, there is difference of opinion as to whether the gneisses constitute the basement for the low-grade supracrustals or intrude them also. This question has become all the more important because some authors have recently suggested that only the low-grade supracrustals are Dharwars.

*italics ours.

The controversy can be resolved if the scope of the terms "Dharwar System" now rechristened as "Dharwar Supergroup" and "Peninsular gneiss" can be defined. Pichamuthu^{68,101} has drawn attention to the clause in the International Stratigraphic Guide¹⁰² that when a stratigraphical sequence has originally been given a name, the same name cannot be used for a part of it. If a sequence with a particular name is divided, separate names should be given to the parts. Therefore, the name Dharwar Supergroup cannot be applied to a part of the supracrustal sequence composed of only low-grade supracrustals in Karnataka. It is suggested that the entire supracrustal sequence developed during the early Precambrian megacycle in the Dharwar craton could be referred to as the Dharwar Group or Dharwar Sequence, and this could be subdivided into Sargur Subgroup, Bababudan Subgroup, Chitradurga Subgroup, etc. The Peninsular gneisses as far as they are synkinematic with reference to Dharwar deformation cycle should be considered as younger than the supracrustals. (Although Smeeth⁸ stated that the Peninsular gneisses were younger than the Dharwars, he held the view that there was a sialic base that was reconstituted, which indicates that relicts of basement gneisses could be present in the Peninsular gneisses.) Adoption of these suggestions :

- (i) will not violate any of the clauses in the International Stratigraphic Guide;
- (ii) will not hinder detailed classification of the supracrustals or gneisses;
- (iii) will account for the structural unity noticed in the low- and high-grade supracrustals;
- (iv) will explain the synkinematic deformation features in the Peninsular gneisses and the general absence of post-crystalline deformation;
- (v) will account for the observed difference in the composition of the granitoid pebbles in the Dharwar conglomerates and the Peninsular gneisses in their vicinity;
- (vi) will lead to an understanding as to why high-grade metamorphic minerals or rocks are absent as detritus in the Dharwar sediments;
- (vii) will explain the mixed ortho- and para-nature of the Peninsular gneisses; and
- (viii) will account for the probable overlapping nature of the ages of greenstones and gneisses.

7. Supracrustal-Granulite and Gneiss-Granulite Relationship

The following questions arise when dealing with the problem of the supracrustal-granulite and gneiss-granulite relationship :—

- (1) Is the granulite province tectonically contiguous with the greenstone-granite province ?
- (2) Are the supracrustals and gneisses of the low-grade terrian the precursors of granulites such as khondalites and charnockites ?
- (3) Are all the charnockites of one generation ?

A proper answer to these questions could provide a basis for understanding the evolution of the continental crust during the Archaean.

Contiguity of the Greenstone-Granite and Granulite Provinces

Fermor¹⁰³ distinguished the charnockite (high-grade) and non-charnockite (low-grade) provinces in the Archaean terrain of India. The granulite province has recently been subdivided into cratonic granulite and coastal granulite belts based on gravity data.⁸⁴ The Eastern Ghat orogenic belt coincides with the coastal granulite belt. The cratonic granulite belt is in continuation southwards of the Dharwar craton. These gravity studies by Subrahmanyam⁸⁴ do not indicate a break between the greenstone-granite province and the cratonic granulite terrain, and, therefore, the two have been considered as forming part of a contiguous block. As mentioned earlier, Pichamuthu¹⁰⁴, Rama Rao⁷ and Shackleton⁸³ have observed that the greenstone-granite belts by progressive metamorphism pass into the granulite region. In the transitional zone, the high-grade supracrustals and gneisses exhibit structures identical in style and sequence with those in the greenstone belts. Some granulite belts mimic the structure-controlled map patterns of the greenstone belts⁵⁸. These evidences suggest that the greenstone-granite and the cratonic granulite province are tectonically contiguous.

Precursors of Granulites

Khondalites and charnockites are the two dominant rock formations of the granulite tracts. The khondalite assemblage consists of immature quartzites, metapelitic schists and gneisses, metacarbonate calc-silicate rocks, and metamorphosed iron and manganese formations. These were considered to be equivalent to the Middle Dharwars.¹⁰⁵ The high-grade metasediments represented by such rock formations in the southern part of the Dharwar craton have, however, been recently considered as belonging to the Sargur Group which is separated from the khondalites and Dharwar supracrustals.^{5,11} Janardhan *et al.*,¹⁰⁶ and Srinivasan and Sreenivas¹⁰⁷ have considered them as intermediate pressure facies series equivalents of the khondalites which generally show low pressure facies series metamorphism.

Whereas Janardhan *et al.*,¹⁰⁸ Swami Nath and Ramakrishnan⁵ and Radhakrishna⁴ believe that these sediments are older than the Dharwar supracrustals, Pichamuthu⁶⁸ and Pichamuthu and Srinivasan⁵⁸ consider that these metasediments are high-grade equivalents of sediments developed mainly in the lower sections of the Dharwar stratigraphic column.

Viswanathan¹⁰⁸ has drawn attention to the komatiitic composition of some of the mafic charnockites in South India which are similar to some of the mafic volcanics in the Dharwar greenstone belts. In the transitional zone the quartzo-feldspathic gneisses grade into the grey gneisses of the greenstone granite province, and the high-grade gneisses have compositional similarity with the felsic charnockites. This has led to the suggestion that the development of charnockite from these gneisses has largely been isochemical.^{88,92,106}

The ultramafic-mafic complexes in the granulite terrains are known to be of the nature of deformed layered complexes^{27,53,109}. Such layered complexes also occur in the greenstone belts in the Dharwar craton as, for example, in the Nuggihalli schist belt.^{50,53} Pillow structures have been reported from the ultramafics of both greenstone and granulite terrains^{46,110}. The komatiitic composition of ultramafic rocks from the greenstone and granulite regions have also been reported.^{43,47,111} Whereas chromite is associated with ultramafic rocks in the greenstone belts, it occurs in both ultramafic and anorthosite members in the granulite terrain.

These overall similarities together with the structural contiguity of the greenstone and granulite terrains lead to the conclusion that members of the greenstone belts could be the precursors of granulites.⁵³ There are, however, some points that require further clarification :

1. The differences in the rare earth compositions of the mafic inclusions in the gneisses and granulites as compared to the metavolcanics in greenstone belts;¹¹² inclusions show ocean floor basalt composition whereas volcanics of greenstone belt have marginal basin basalt affinity. It is known that both types occur in greenstone belts also as for example in the Kolar schist belt.¹¹³ Also a range of REE patterns and abundances characterise the metavolcanics of the greenstone belts.⁵⁵ It is not clear whether these differences reflect the early differentiation of the crust into various volcano-tectonic environments or a secular change in the nature of the crust.

2. There is an apparent paucity of metagreywacke suite sediments in the granulite terrain. Is this due to the development of granulites from sediments of a different tectonic environment of sedimentation as compared to those of greenstone belts or is it because greywackes occur high-up in the sequence in greenstone belts and, therefore, participated less in the generation of granulites ?

3. Whereas titaniferous magnetite is an important constituent in the ultramafic-mafic layered complexes of greenstone belts, it appears to be absent in the layered complexes of the granulite terrain.

Age of Charnockites

Pichamuthu⁹⁰ distinguished charnockites of two different ages in the Dharwar craton. An earlier generation of regional metamorphic gneissic charnockites to which most of the charnockites belong and a later generation of anatectic felsic charnockites. Both these types of charnockites were considered to be younger than the gneisses and supracrustals (Peninsular gneiss and Dharwar). It was suggested that the two generations of charnockites were separated by an episode of dyke activity, represented by dykes consisting of minerals that show clouding. This clouding was attributed to the regional thermal episode accompanying the formation of the second generation charnockites.

Devaraju and Sadasiviah¹¹⁴ and Narayanaswami¹¹⁵ believed that all the charnockites are older than the gneisses and that the gneisses were formed by retrogression of charnockites. Recently, Janardhan *et al.*⁸⁸ and Raith *et al.*⁸⁷ supporting the view that the gneisses are older have considered that the charnockites in South India were developed during a 2600m.y. old event. Janardhan *et al.*⁸⁸ believe that there is no evidence for more than one generation of charnockites and explain the clouding in dykes as due to the deuteritic activity during the late stage of emplacement of the dykes themselves, and not due to a regional thermal episode as believed by Pichamuthu.⁹⁰ However, this does not explain why such deuteritic alteration was confined only to the dykes of various petrographic types in the granulite terrain while dykes of similar composition and textures in the adjoining non-charnockitic region were unaffected. The retrogression of the charnockites to gneisses has been attributed by Janardhan *et al.*⁸⁸ to the autoretrogression in the late stages of charnockite formation. More detailed studies are required for resolving these controversial issues.

8. Future Trends

The geology of the Dharwar craton as reviewed in the foregoing sections shows that although this is one of the better studied early Precambrian terrains in India, there are still many lacunae in our knowledge. In order to increase our knowledge of the geology of this terrain further work is essential, and some of the lines on which these investigations may be pursued are indicated below :

1. At the outset it is very necessary to standardise the stratigraphical nomenclature for the Dharwar craton.

2. The early Precambrian sequences of the craton are structurally strongly disturbed by superposed folding. Detailed structural investigations have to be carried out for evolving an acceptable stratigraphic succession. These studies are of fundamental importance for establishing the internal stratigraphy of supracrustal belts and the mutual relationship between supracrustals, gneisses, and granulites. Such investigations will also reveal the nature of deformation in the Archaean as evident in the Indian shield.

3. The P-T-X conditions of metamorphism are being investigated in the Dharwar craton by modern methods utilising the distribution coefficients of elements in co-existing minerals. Relation of metamorphism to the structural evolution of the rock should also be investigated. A study of the metamorphism of syngenetic ore deposits can throw a great deal of light on the metamorphism of the host rock. Incidentally, these studies will have a bearing on the redistribution and localisation of ore deposits.

4. An intensive study should be made of the sedimentary rocks, especially their primary sedimentary structures and sedimentology. These data will supplement structural investigations for erecting the stratigraphical succession, can lead to an understanding of the Archaean sedimentary basin configuration and tectonic environments of sedimentation. The Dharwar-greenstone belts of Archaean age are somewhat unique because of the large-scale development of limestones and banded manganese formations in addition to the banded iron formations which are well developed in greenstone belts in other parts of the world. These non-detrital sediments therefore, need special attention. Field and petrological studies supported by geochemistry including REE and stable isotopic data, can throw light on the palaeoenvironments (physico-chemical, biochemical) influencing Archaean sedimentation as also the subsequent modifications they have suffered due to metamorphism.

5. Although a large amount of major and trace element data have accumulated on the rock formations of the Dharwar craton, the lack of data on critical high field strength elements and rare earth elements has inhibited our understanding of the nature of the precursors especially of mafic and ultramafic rocks of the supracrustal sequences. It has not been possible for deciphering the nature and origin of mafic and ultramafic melts based on high quality geochemical criteria, thus resulting in a gap in our knowledge of the Archaean mantle processes and lithospheric evolution.

6. Geological mapping of the gneissic and granulite country in the Dharwar craton has been neglected. For a proper understanding of the Archaean crustal evolution, it is necessary to map the gneissic and granulite terrain as has been done in Greenland and in the Fennoscandian shield. Structural studies of gneisses to demarcate prekinematic, synkinematic and

late-to post-kinematic gneisses can lead to the identification of basement gneisses from amidst the remobilised gneissic complex.

Geochemical studies following the detailed field investigations are necessary for deciphering the origin of gneisses, granites, and charnockites. Detailed field and geochemical investigations can lead to the discovery of many industrial and strategic mineral deposits.

7. Geochronological data are totally inadequate for the Dharwar craton. The time scale for the events in the craton needs to be worked out based on strontium, lead, and neodymium isotopic systems on samples collected from areas where structural and metamorphic histories have been investigated. Such isotopic studies will also provide the necessary criteria for understanding the evolution of the continental lithosphere during the Archaean times.

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